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Calcaneus radiograph as a diagnostic tool for sexual dimorphism in Egyptians

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ABSTRACT

Measurements of calcaneus have been shown to be sexually dimorphic in American whites and blacks, Italians and South African whites and blacks. Since the validity of discriminant function equation in sex determination is population specific, the aim of the present study was to derive similar equations for the calcanei of Egyptians. Lateral radiographs of the ankles of 204 Egyptians aged 20–70 were analyzed with regards to sexual dimorphism, consisting of 104 males and 100 females. X-ray films were obtained from Minia Forensic Department. Six measurements were taken for every calcaneal X-ray film, three linear and three angular measurements. Data were analyzed by SPSS version 17, An independent samples *t*-test and discriminant function analysis were done. All linear measurements, but not angular, showed significant sexual differences. Maximum length was found to be the most sexually dimorphic (90.2%). Combination of maximum length with minimum height gave the same result of all linear measurements (92.6%) which was more than given by individual variables (81.4–90.2%).

1. Introduction

Determination of sex is considered one of the first essential step in positive identification.[1] Determining the individual characteristics of individuals involved in traumatic events, i.e. aircraft crashes, automobile accidents, fire disasters, can be problematic in cases where massive trauma is involved.[2] Sex is the first demographic factor that is determined because it reduces the number of possible matches by 50%.[3] Also sex estimation is a fundamental step for establishing the biological profile of an individual.[4]

Measurements of the calcaneus have been shown to be sexually dimorphic in American whites and blacks,[5] Central Europeans,[2] Italians,[6] South African whites,[7] and South African blacks[8]; however this technique is limited to cases where the skeletal elements are exposed and available for direct measurements. As radiograph presents an exact image of bone,[9] Damon[10] mentioned that sex determination, age at death, race and stature of the decedent are all anthropological parameters that can be evaluated radiographically to help identify the decedent.

Riepert et al.[2] described a technique for employing radiographs of the calcaneus for estimating sex, the principal advantage is that it is not necessary to have the calcaneus exposed.

Since the validity of discriminant function equation in sex determination is population specific,[11–13] the aim of the present study was to derive similar equations for Egyptians, and to test the validity of the derived equations.

1.1. Subjects and methods

Lateral radiographic projections of the right and left ankles of 204 persons (104 males and 100 females) aged 20–70 years were analyzed. Fischer X-ray set was used to take the X-ray imaging. Set volts 24 VDC, mirror X-ray rating to 150 kvp, 2.0 MM Al.Equiv, 50/60 Hz, 150 W. Lateral views were done using 60–65 kv, 10–12 mA/s. with a distance 100 cm. The radiographs were taken from Minia forensic department for persons who sent by prosecution for forensic examination, fractures and any abnormalities were excluded from the study. Age and sex distribution was shown at Fig. 1. According to Riepert et al.,[2] length, height and minimum height, tuber angle [Boehler's angle (Boehler[14])], tuber plantar angle and front angle are defined as shown in Figs. 2 and 3. Measurements were made using sliding calipers graduated to 0.1 mm and protractors graduated to 0.5°. These measurements were done for each of 204 X-ray films.

1.2. Statistical analysis

The data were analyzed using SPSS statistical package version 17. For each of the measurements, descriptive statistics including

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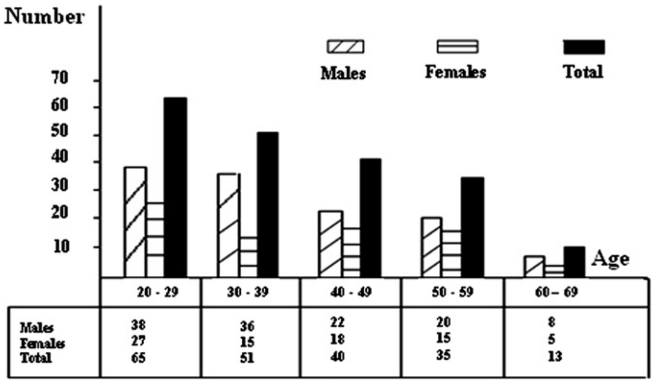

Fig. 1. Age and sex distribution.

mean and standard deviation were obtained. After using the independent samples t-test to establish that a significant difference existed between the male and female mean values for each of the measurements, direct and stepwise analyses were performed on the significant variables.[7] Univariate analysis was also performed on each of the variables in order to obtain demarking points (average of male and female mean values) that could be used for fragmentary bones in which all parameters are not measurable. All measurements were used to select the variable or combination of variables that best discriminates between sexes. Direct analysis of individual variables was performed to develop formulae to allow sex determination from fragmentary remains.

2. Results

Males presented with significantly greater ($P < 0.001$) mean values for linear measurements, but not for angular ones, than females (Table 1) indicating the presence of significant sexual dimorphism in linear measurements of the Egyptian calcaneus. The average of the male and female mean values gives the demarking points, the sum of male and female means divided on 2 (according to Bidmos and Asala[8]) (Table 2), which is a rapid way of determining sex from single variables. A measured value higher than the demarking point classifies an individual as male and a lower value suggests female. The percentage accuracy in correct sex classification for each of the linear variables is also presented (Table 2). Length, minimum height and height are sexually dimorphic variables with accuracies of 90.7, 81.8 and 81.6%, respectively.

Tables 3 and 9 show direct, univariate, and stepwise discriminant function analysis. The three significant linear variables entered the analysis. From Tables 3 and 4, discriminant function (df) score equation can be formulated for the functions using the df coefficients.

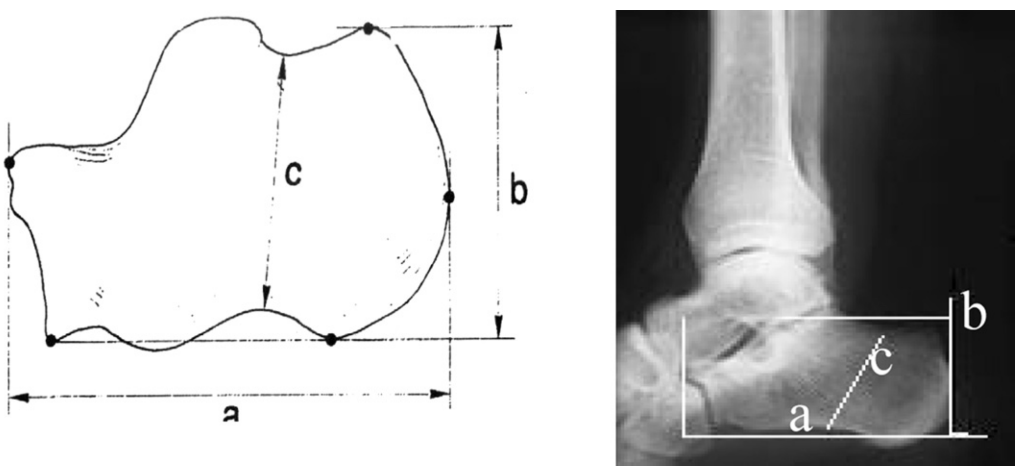

Fig. 2. Measurement of the calcaneus: a, length; b, height; c, minimum height.

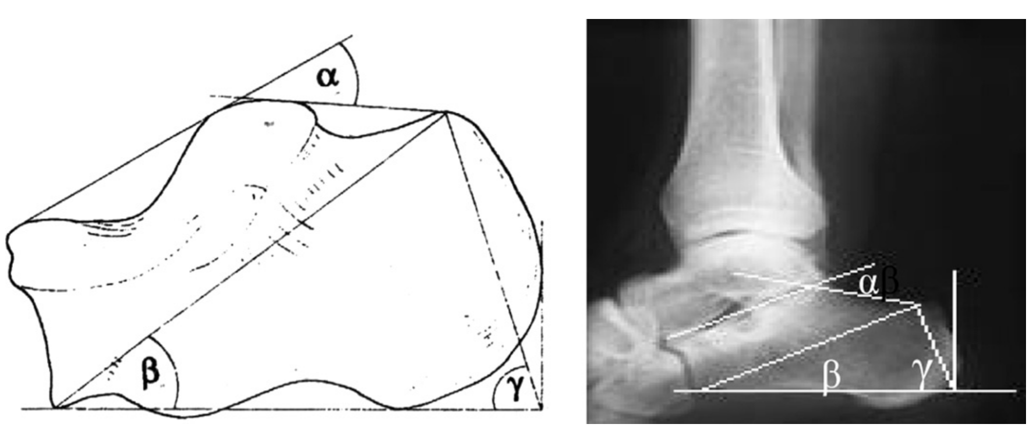

Fig. 3. Angles of the calcaneus: α, tuber angle; β, front angle; γ, tuber plantar angle.

Table 1
Descriptive statistics of male and female values and independent samples *t*-test.

Variables	Sex	Number	Min.	Max.	S.D	Mean mm	*t*-Value	*P* value
Length	F	100	66	83	3.8	73.6800	16.92	0.00
	M	104	72	95	5.1	84.3462		
Height	F	100	36	48	3.5	41.4100	13.16	0.00
	M	104	40	56	3.5	47.9423		
Min. height	F	100	31	41	3.2	34.5900	13.36	0.00
	M	104	32	48	3.1	40.2981		
T.P. angle	F	100	68	78	4.6	72.1285	1.92	0.05
	M	104	62	77	2.4	72.5520		
F. angle	F	100	30	44	3.7	37.5436	1.35	0.17
	M	104	30	50	3.8	38.2580		
T. angle	F	100	20	42	4.6	33.9480	1.18	0.23
	M	104	23	55	5.8	34.2400		

P value is significant when $P < 0.05$.

Table 2
Demarking points (in mm) for sex differentiation using individual variables.

Variables	Demarking points	Accuracy %
Length	Female < 79.01 < Male	90.7%
Height	Female < 44.67 < Male	81.6%
Minimum Height	Female < 37.44 < Male	81.8%

Using these equations for any calcaneus length, height and minimum height, calculating their score in the discriminant function if an individual person score on the df (calculated by: $df = 0.726 \times L + 0.178 \times H + 0.367 \times M$), if the result is above 78.52 then the individual is considered male and if the df score is below 78.52 the individual is considered female.

From these discriminant function coefficients df value for males and females can be calculated as the follows:

$$\begin{aligned} df\ (\text{males}) &= 0.726 \times L + 0.178 \times H + 0.367 \times M \\ &= 0.726 \times 84.35 + 0.178 \times 47.95 + 0.367 \times 40.29 \\ &= 83.50 \end{aligned}$$

$$\begin{aligned} df\ (\text{females}) &= 0.726 \times L + 0.178 \times H + 0.367 \times M \\ &= 0.726 \times 73.68 + 0.178 \times 41.41 + 0.367 \\ &\quad \times 34.59 \\ &= 73.55 \end{aligned}$$

where L is the length; H, height and M, minimum height.

From these two values, we can calculate a cut point for the df as the follows:

$$df = df\ (\text{males}) + df\ (\text{females})/2 = 83.50 + 73.55/2 = 78.52$$

Table 5, shows classification results: 92.6% of original grouped cases correctly classified by direct df analysis. By univariate analysis, accuracy was highest with usage of length variable and was 90.2%. By stepwise analysis, Tables 7–9, the data revealed that the length and minimum height are the best two variables can be used together in sex determination with a percentage of 92.6% which is the same result obtained by the three linear measurements together.

Table 4
Discriminant function analysis for Egyptians.

Function analysis	Stand. coefficient	Structure matrix	Group centroid	Accuracy
Direct:				
Length	0.726	0.867	Male: 1.340	92.6%
Height	0.178	0.684	Female: 1.394	
Min. height	0.367	0.674		
Univariate:				
Length	1.000	1.000	M1.162, F 1.209	90.2%
Height	1.000	1.000	M0.904, F −0.940	81.4%
Min. height	1.000	1.000	M0.917, F−0.954	81.9%
Stepwise:				
Length	0748	0.872	M1.333, F−1.386	92.6%
Min. height	0505	0.688		
Height		0.611		

Min. height, minimum height; M, male; F, female.

3. Discussion

This study employed radiographs of the calcaneus in sex determination. Radiographs of this region quite easily taken thus make it possible to identify an unknown corpse by x-ray comparison of the calcaneus.[15]

However, a radiograph presents an exact image,[9] there is a problem that the object on X-ray is slightly larger than in reality. In addition different X-ray morphology may result from angulations with respect to the X-ray beam.[2] That is the reason why an accurate X-ray technique (e.g. 100 cm focus film distance. X-ray beam exactly lateral) is necessary. In general, however, due to regular proportions of the calcaneus, it doesn't seem to be sensitive to differences in the X-ray technique when compared to other regions of the body (e.g. the complex structure of vertebral column).[2]

All variable measurements were less than the measurements taken by Riepert, et al.,[2] on a sample of European population (e.g. the length for Egyptian males and females were 84.39 & 74.58 mm, respectively, and for European males and females were 89.8 & 82.0). This difference can be the result of genetic factors, environmental factors affecting growth and development (nutrition, physical activity, pathological, etc.), and the interaction of previous factors.[16]

Independent samples *t*-test was done for all males and females samples, the results revealed that there was significant difference between male and female calcanei in the three linear measurements only but not with the three angular measurements, we got a significant *P* value in the length, height and minimum height, these results are in agree with a study done for Europeans by

Table 3
Summary of canonical discriminant functions for Egyptians.

Functions	Eigen value	% of Variance	Cumulative %	Canonical correlation	Wilks lambda	Chi sq.	Sig.
Direct: three linear variables	1.887	100.0	100.0	0.808	0.346	212.592	0.000
Univariate:							
Max. L.	1.418	100.0	100.0	0.766	0.414	177.938	0.000
Max. H.	0.859	100.0	100.0	0.680	0.538	124.887	0.000
Min. H.	0.884	100.0	100.0	0.685	0.531	127.583	0.000
Step wise	1.865	100.0	100.0	0.807	0.349	211.557	0.000

Table 5
Percentage of cases correctly classified.

Functions	Variables	Total	Male		Female		Accuracy
			%	No.	%	No.	
Direct	L, H, Min. H	204	89.4	93/104	96	96/100	92.6%
Univariate	L	204	87.5	91/104	93	93/100	90.2%
	H	204	82.7	86/104	80	80/100	81.4%
	Min. H	204	81.7	85/104	82	82/100	81.9%
Stepwise	L, Min. H	204	89.4	93/104	96	96/100	92.6%

L, length; H, height; Min. H, minimum height.

Table 6
Stepwise statistics:variables entered/removed.[a,b,c,d]

Step	Entered	Wilks' Lambda							
						Exact *F*			
		Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	Length	0.414	1	1	202.000	286.498	1	202.000	0.000
2	Min. height	0.349	2	1	202.000	187.420	2	201.000	0.000

At each step, the variable that minimizes the overall Wilks' Lambda is entered.
[a] Maximum number of steps is 6.
[b] Minimum partial *F* to enter is 3.84.
[c] Maximum partial *F* to remove is 2.71.
[d] F level, tolerance, or VIN insufficient for further computation.

Riepert et al.[2] which also found that there is significant differences between the linear measurements more than the angular measurements. The significant differences between males and females calcanei are due to differences in body size and in muscular activity of the individual, also cortical bone in males has higher growth than in females.[17]

Linear variables displayed significant sex differences between male and female mean measurements, thereby showing sexual dimorphism of calcaneus of Egyptians. This agree with previous studies for Europeans.[2] Also agree with studies done on calcaneus bone itself, not radiographs, for Italians,[6] African whites and blacks.[7,8] However the average accuracy obtained from the present study (81.6%–90.7%) using demarking points for individual variables is higher than that (73%–86% and 74%–79%) for South Africans whites and blacks respectively,[7,8] and that (69%–84%) obtained for Southern Italian population using discriminant function analysis.[5] The results of the study that done by Russo[18] indicated that metric triats of the talus and calcaneus are good indicators of sexual dimorphism.

By using direct and stepwise discriminant function analysis, it was found that the accuracy of using three linear radiographic measurements in sex determination for Egyptians was (81.4–92.6%). Similar results obtained by Bidmos and Asala,[7] when they use direct and stepwise discriminant function analysis, the accuracy of sex determination was 88–92%. At the same time, it was found for African blacks, 79–86%,[7] and for Italian was 76–85%.[5]

Univariate discriminant function analysis, revealed that length of calcaneus is the best single variable can be used for sex determination, the accuracy was 90.2%, by using height measurement, accuracy was 81.4%, lastly, by using minimum height, accuracy was

Table 7
Variables in the analysis.

Step		Tolerance	*F* to remove	Wilks' lambda
1	Length	1.000	286.498	–
2	Height	0.940	104.719	0.531
	Min. height	0.940	37.117	0.414

Min height, minimum height.

Table 8
Variables not in the analysis.

Step		Tolerance	Min. tolerance	*F* to enter	Wilks' lambda
0	Length	1.000	1.000	286.498	0.414
	Height	1.000	1.000	173.424	0.538
	Min. height	1.000	1.000	178.479	0.531
1	Height	0.917	0.917	30.862	0.358
	Min. height	0.940	0.940	37.117	0.349
2	Height	0.375	0.375	1.563	0.346

Min. height, minimum height.

Table 9
Wilks' lambda.

Step	Number of variables	Lambda	df1	df2	df3	Exact F			
						Statistic	df1	df2	Sig.
1	1	0.414	1	1	202	286.498	1	202.000	0.000
2	2	0.349	2	1	202	187.420	2	201.000	0.000

81.9%. So, length measurement was the most sexually dimorphic for Egyptian' calcaneal radiograph, this result is similar to that of African blacks, as the length measurements were the most sexually dimorphic with average accuracy 85%.[8] But in contrast with African whites, as breadth measurements were the most sexually dimorphic.[7] This contrasting finding support an earlier observation of King et al.,[19] that showed the existence of population differences in sexual dimorphism between dimensional groups.

From Table 6, it could be noticed that there is little percentage of misclassification in sex determination (7.4–18.6%) can be explained by dividing misclassification into two kinds: constant, wrong classified cases in all functions (i.e. in all variables) (males of reduced dimensions or very strong musculature females) and inconstant, cases that are included in one sex in some functions and other times in others (slender males and robust females with body dimensions similar to the average of each sex).[20]

4. Conclusion

This study has shown that linear measurements of calcaneus X-ray of Egyptians is sexually dimorphic. The level of accuracy obtained from the use of these linear measurements was 92.6. By using univariable analysis, length gave accuracy of 90.2%.With the use of the most sexually dimorphic variables; length and minimum height gave an accuracy of 92.6% which was the same result achieved by the three linear measurements. So, the two variables will provide better and easier method for sex determination. The equation derived from this study should be used with caution in cases when only calcaneus or only its X-ray is available for sex determination.

Conflict of interest

Estimation of sex from bone radiograph.

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Ethical approval

This work was approved by ethical committee of Faculty of Medicine, Minia University, for human experimentation.

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